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**Pre-equilibrium dileptons look thermal**

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**Abstract**

The dilepton mass distribution from pre-equilibrium matter in ultrarelativistic nuclear collisions is indistinguishable from a thermally produced distribution.

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Dileptons may provide one of the few windows to the early behavior of the hot strongly-interacting matter produced in ultrarelativistic nuclear collisions [1]. Because they interact only electromagnetically, they escape from the collision volume at the earliest stages of the collision, in contrast to strongly-interacting particles that escape only at the end of the collision. The dilepton mass distribution from the equilibrating hadronic matter has recently been calculated for the early stages of central Au+Au collisions at  $\sqrt{s} = 200$  GeV/nucleon by Geiger and Kapusta [2], using a parton cascade model. In this Letter, we show that their distribution is indistinguishable from one produced by a thermally equilibrated quark gluon plasma (QGP).

We calculate the dilepton mass distribution in the same manner as Kajantie, Kapusta, McLerran and Mekjian [3], assuming boost-invariant longitudinal expansion and no transverse expansion [4]. In this scenario, assuming an ideal gas of massless quarks and gluons, the temperature,  $T$ , can be obtained from the proper time,  $\tau$  (because entropy is conserved):

$$\tau T^3 = \text{constant}. \quad (1)$$

Thus, once the temperature is known at one proper time, it is known at all proper times. We fix the value of the constant from the temperature obtained at the end of the parton cascade simulation,  $T_f = 300$  MeV at  $\tau_f = 2$  fm/c [2].

The thermal dilepton mass,  $M$ , distribution is

$$\frac{d^2 N}{dM^2 dy} = \int d\tau A \tau \left. \frac{dN}{dM^2 d^4 x} \right|_T, \quad (2)$$

where  $A$  is the cross-sectional area of the region of hot matter (constant, in the absence of transverse expansion; we use  $A = 150$  fm<sup>2</sup>). Here

$$\left. \frac{dN}{dM^2 d^4 x} \right|_T = \frac{5 \alpha^2}{18 \pi^3} M T K_1(M/T) \quad (3)$$

is the thermal production rate from QGP [3], where  $\alpha$  is the fine-structure constant. We use the standard high energy conventions that  $\hbar = c = k_B = 1$ .

We begin our simulation at  $T = T_0$ , and end (as the parton cascade calculation does) at  $T_f = 300$  MeV. The total dilepton production rate is integrated by rewriting the proper time integrals as temperature integrals, following [3].

$$\frac{d^2 N}{dM^2 dy} = \frac{5 A \alpha^2 \tau_f^2 T_f^6}{6 \pi^3 M^4} [H(M/T_0) - H(M/T_f)], \quad (4)$$

where

$$H(z) = z^2 (8 + z^2) K_0(z) + 4z (4 + z^2) K_1(z). \quad (5)$$

The cascade results are fit extremely well by the thermal distribution with  $T_0 = 950$  MeV ( $\tau_0 = 0.063$  fm/c), as shown in Fig. 1.

It is obvious from the figure that the non-equilibrium production cannot be distinguished from the equilibrium production. The initial proper time needed for the thermal production is very small, much smaller than the thermalization time (0.3

fm/c) estimated from the parton cascade calculation [2]. By the uncertainty principle, it is impossible to define the energy at that time to an accuracy of more than about 3.1 GeV  $\gg T_0$ , so the distribution of low energy quarks and gluons might not be the same as for a thermal gas of free quarks and gluons. However, as long as the total entropy density and the high energy tails of the particle distributions are the same as for a free thermal gas, the high mass dilepton production rate will be unaffected by the non-equilibrium behavior of the low energy components of the QGP.

At proper time  $\tau_0$ , the hot matter is contained in a region of longitudinal width 0.063 fm. The lowest mode then has energy 1.55 GeV, slightly higher than the transverse momentum cutoff,  $p_{\perp cut} = 1.5$  GeV, of [2]. Thus, the value of  $T_0$  might be determined by the value of  $p_{\perp cut}$  used in the parton cascade model.

It is possible that this apparent thermal fit is just a coincidence; however, it is also possible that the high energy tails of the quark and gluon distributions are approaching thermal and chemical equilibrium faster than the low energy quarks and gluons that comprise the bulk of the QGP. In either case, the result presented here illustrates the difficulty of extracting information about the non-equilibrium QGP from studies of high mass dileptons produced in ultrarelativistic nuclear collisions.

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## Figure caption

1. Comparison of thermal ( $T_0 = 950$  MeV) and non-thermal dilepton mass distributions.

